

# Superconducting phase transition in $\text{YNiGe}_3$ , a non- $f$ -electron reference to the unconventional superconductor $\text{CeNiGe}_3$

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## Abstract

A polycrystalline sample of  $\text{YNiGe}_3$ , being a non-magnetic isostructural counterpart to the unconventional pressure-induced superconductor  $\text{CeNiGe}_3$ , was studied by means of specific heat and electrical resistivity measurements at temperatures down to 360 mK and in magnetic fields up to 500 Oe. The compound was found to exhibit an ambient-pressure superconductivity below  $T_c = 0.46$  K. The superconducting state in  $\text{YNiGe}_3$  is destroyed by magnetic field of the order of 500 Oe.

*Keywords:* A. superconductors, D. electronic transport, D. heat capacity

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## 1. Introduction

The compound  $\text{CeNiGe}_3$ , crystallizing in the orthorhombic  $\text{SmNiGe}_3$  type structure,[1] is an antiferromagnetically ordered Kondo lattice with the Néel temperature  $T_N = 5.5$  K and the characteristic Kondo temperature  $T_K \sim T_N$  [2]. Upon applying hydrostatic pressure,  $T_N$  increases up to about 8 K at  $P_{\text{max}} \approx 3$  GPa, rapidly decreases at higher pressure, and finally is suppressed to zero at a critical pressure  $P_c \approx 5.5$  GPa. Most importantly, around this quantum critical point the compound becomes superconducting below about 0.48 K. Analysis of the temperature variation of its electrical resistivity in the normal state revealed an unconventional nature of the superconductivity in  $\text{CeNiGe}_3$ . [3, 4] More detailed investigations of the compound showed that the superconductivity emerges in  $\text{CeNiGe}_3$  not only in the critical region, but also deeply in the antiferromagnetically ordered phase, forming two distinct superconducting domes on the  $P-T$  phase diagram, located around  $P_{\text{max}}$  and  $P_c$ . [5, 6] Nuclear quadrupole resonance (NQR) measurements revealed that the onset of the superconductivity is in both domes a consequence of the presence of the  $4f$  electrons of cerium. [7, 8, 9]

$\text{YNiGe}_3$  was used in our previous studies as an isostructural non-magnetic counterpart to  $\text{CeNiGe}_3$ . [2] The temperature dependencies of its magnetic susceptibility, electrical resistivity and specific heat (measured down to 1.7, 1.5 and 1.8 K, respectively) showed the yttrium phase to be a simple metal with nearly temperature-independent magnetic susceptibility. In the course of our investigations of the  $\text{Ce}_{1-x}\text{Y}_x\text{NiGe}_3$  alloys (to be published elsewhere) we have reinvestigated the electrical resistivity and the specific heat of  $\text{YNiGe}_3$  down to 0.36 K. Here we report on a superconducting phase transition found

in this compound.

## 2. Material and methods

Polycrystalline sample of  $\text{YNiGe}_3$  was prepared by conventional arc melting the stoichiometric amounts of the elemental components (Y 3N, Ni 3N, Ge 5N) in protective atmosphere of an argon glove box. The pellet was subsequently wrapped in a molybdenum foil, sealed in an evacuated silica tube, and annealed at 800°C for one week. Quality of the product was verified by means of x-ray powder diffraction and microprobe analysis, which both showed that the sample was a single phase. Rietveld refinement of the x-ray powder pattern confirmed that  $\text{YNiGe}_3$  crystallizes in the  $\text{SmNiGe}_3$  type structure with the lattice parameters  $a = 4.060(1)$  Å,  $b = 21.529(2)$  Å,  $c = 4.063(3)$  Å, being close to those reported previously.[2] The energy dispersive x-ray analysis of randomly chosen areas on the sample surface resulted in the average composition: Y – 25(1)at.%, Ni – 18(1)at.% and Ge – 57(1)at.%, that corresponds to the formula  $\text{Y}_{1.3(1)}\text{Ni}_{0.9(1)}\text{Ge}_{2.8(1)}$ . The deviation from the nominal composition may be attributed to the fact, that the analysis was performed using internal standards of the spectrometer.

Physical properties of the compound were studied using a commercial Quantum Design PPMS platform, in temperature range 0.36–300 K and in magnetic fields up to 500 Oe, generated by a standard 9 T magnet. The resistivity was measured by a conventional four point AC technique on a bar-shaped sample with electrical contacts made of silver epoxy paste.

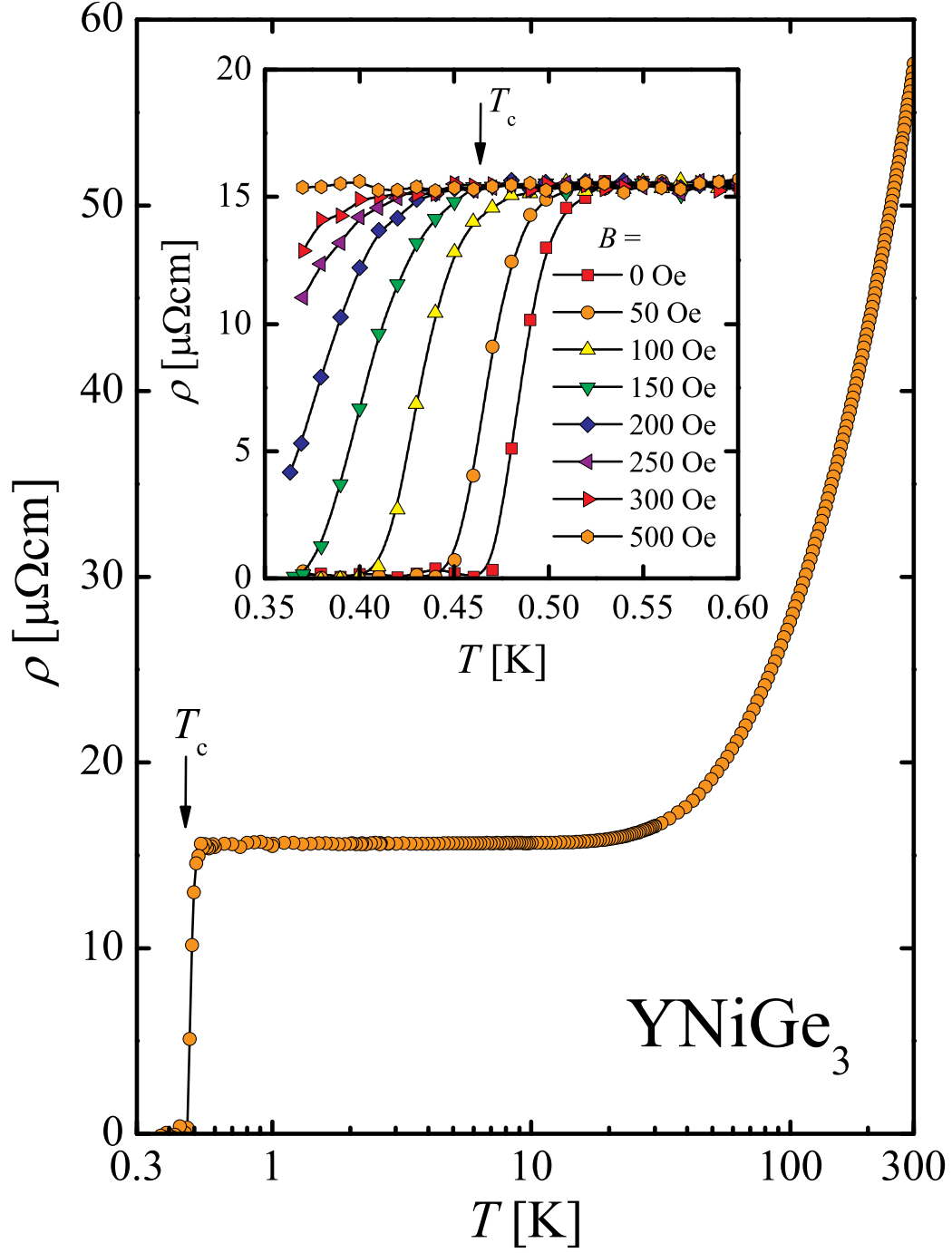


Figure 1: Electrical resistivity of  $\text{YNiGe}_3$  as a function of temperature. The arrow marks the critical temperature  $T_c$  and the solid lines serve as guides for the eye. The inset: evolution of the superconducting phase transition upon applying magnetic field  $B$ ; the values of  $B$  are nominal.

### 3. Results and discussion

Figure 1 presents the temperature dependence of the electrical resistivity  $\rho$  of YNiGe<sub>3</sub> in a semi-logarithmic scale. The overall behaviour of  $\rho(T)$  is similar to that reported previously: [2] upon cooling down,  $\rho$  decreases in a simple metallic manner and saturates below about 10 K. The resistivity remains constant down to the temperature of about 0.50 K, below which a rapid drop of  $\rho$  clearly manifests the onset of superconductivity, with the critical temperature  $T_c = 0.46$  K. Small width of the phase transition, which is less than 8% of  $T_c$ , points at a bulk character of the superconductivity. Presence of a distinct anomaly, that appears in the temperature variation of the specific heat  $C$  of YNiGe<sub>3</sub> just below  $T_c = 0.46$  K (Fig. 2), seems to support the presumption on the intrinsic nature of the superconducting state. Nevertheless, low-temperature magnetic susceptibility measurements are needed to unambiguously confirm the bulk character of the superconducting state in the compound studied.

As seen in the insets to Figs. 1 and 2, the superconducting state in YNiGe<sub>3</sub> is very sensitive on the strength of the magnetic field applied. Upon increasing field,  $T_c$  inferred from the  $\rho(T)$  curve systematically decreases and already at 500 Oe the drop of  $\rho$  is out of the investigated temperature range. Similar behaviour is visible in the specific heat, yet the anomaly in  $C(T)$  quickly broadens with increasing  $B$  and therefore it is hardly visible on the experimental curve already in 70 Oe. Due to low resolution of the magnet used in our experiments (the remanent field was of the order of 10–20 Oe), we were not able to construct and reliably analyse the  $B-T$  phase diagram for YNiGe<sub>3</sub>. Nevertheless, based on the electrical resistivity measurements one

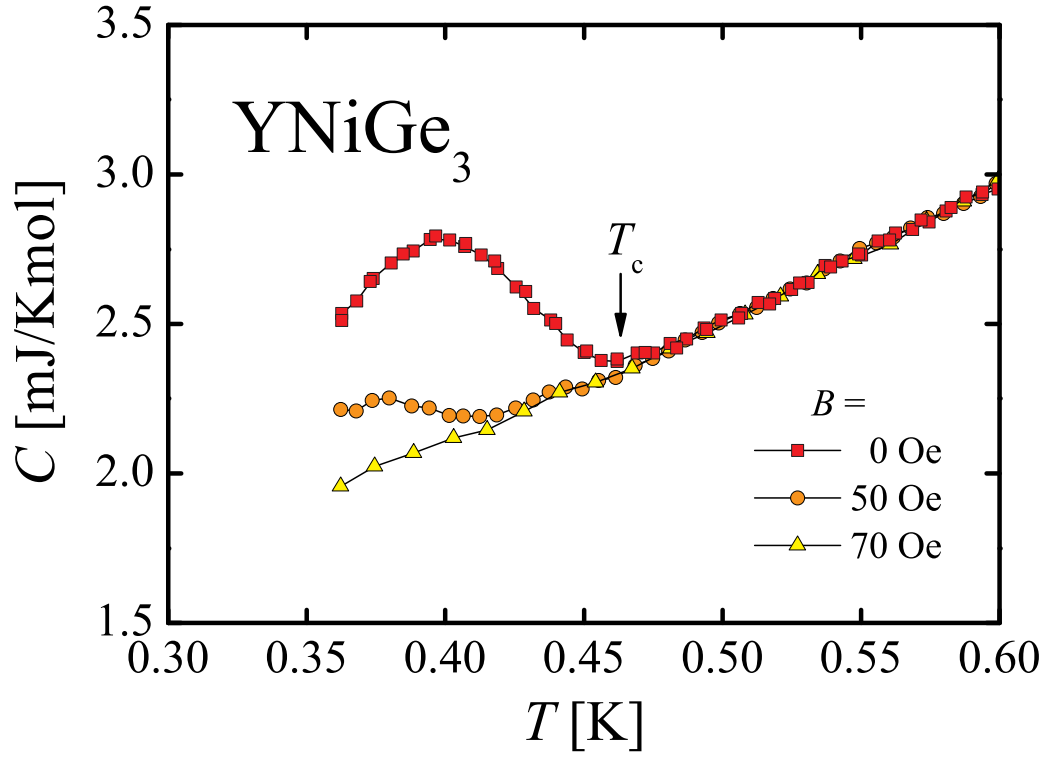


Figure 2: Temperature dependence of the specific heat of YNiGe<sub>3</sub> measured in several different magnetic fields  $B$ ; the values of  $B$  are nominal. The solid curves serve as guides for the eye and the arrow marks the critical temperature.

can estimate the critical field value  $H_{c2}$  to be of the order of 500 Oe.

The small value of  $H_{c2}$  is characteristic of conventional, BCS-like superconductors. However, the observed jump of the specific heat,  $\Delta C/(\gamma_n T_c)$ , is in YNiGe<sub>3</sub> of about 0.50(5) (Fig. 2), which is well below  $\Delta C/(\gamma_n T_c) = 1.43$  expected for an *s*-wave BCS superconductor. Such a distinct deviation of the specific heat jump from the BCS value hints at possible unconventional character of the superconducting state. For example, in YBa<sub>2</sub>Cu<sub>3</sub>O<sub>7</sub>, which is one of the best known high- $T_c$  superconductors,  $\Delta C/(\gamma_n T_c)$  is of about 2,[10] while in the multi-valued gap superconductor MgB<sub>2</sub> the jump in  $C(T)$  is only 0.82.[10] The recently reported noncentrosymmetric strongly-coupled superconductor Mo<sub>3</sub>Al<sub>2</sub>C has  $\Delta C/(\gamma_n T_c)$  equal to 2.28.[11]

#### 4. Conclusions

The compound YNiGe<sub>3</sub> was found to exhibit an ambient-pressure superconductivity below  $T_c = 0.46$  K, which is close to the maximal  $T_c$  evidenced in CeNiGe<sub>3</sub> around the quantum critical point.[3, 4, 5, 6] In this context it is worth noting that substitution of Ce by Y results in 6%-reduction of the unit cell volume of the system, which can be roughly considered as equivalent to high hydrostatic pressure. Therefore, the finding of the superconductivity in YNiGe<sub>3</sub>, which does not contain *f*-electrons, may shed new light on the character of the superconductivity in the isostructural CeNiGe<sub>3</sub> compound.

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